Title

Separation of State and Valuation in Adaptive Control Systems:
A Structural Constraint for Stability Under Uncertainty

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Abstract

We introduce the Separation of State and Valuation (SVS) principle, a structural constraint for decision-making in systems operating under uncertainty. The principle enforces a strict separation between state representations, which describe the system condition, and valuation signals, which capture uncertainty, residuals, or confidence measures.

We show that direct coupling between valuation and control action introduces a feedback pathway that can amplify noise, induce instability, and lead to overly conservative or reactive behavior. SVS eliminates this pathway by requiring that operational decisions depend exclusively on the reconstructed state, while valuation is restricted to meta-level processes such as mode selection, validation, and supervision.

The proposed framework is compatible with existing approaches including model predictive control (MPC), observer-based control, and safety-constrained architectures. Its relevance is illustrated in the context of plasma control systems, where uncertainty and safety constraints interact strongly.

SVS provides a minimal yet generalizable structural refinement that improves stability, interpretability, and robustness in complex adaptive systems.

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1. Introduction

Control systems operating in complex environments must simultaneously handle:

- incomplete observability
- measurement noise
- model uncertainty
- safety constraints

In many architectures, uncertainty-related quantities such as residuals, confidence scores, or variance estimates are directly or indirectly incorporated into the control law. While this is often intended to improve robustness, it introduces a critical structural issue:

> the system may react not only to the physical state, but to its uncertainty about the state.

This conflation of physical and epistemic quantities can lead to:

- amplification of measurement noise
- oscillatory behavior
- overly conservative or unstable responses

We propose that this issue is fundamentally architectural rather than algorithmic.

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2. Problem Formulation

Consider a dynamical system:

x_{t+1} = f(x_t, u_t, \epsilon_t)

with observation:

$$y_t = h(x_t) + \eta_t$$

A reconstructed state is obtained:

$$z_t = \mathcal{R}(y_{0:t})$$

In addition, systems often compute a valuation signal:

$$v_t = \mathcal{V}(y_t, z_t)$$

capturing:

- uncertainty
- residuals
- confidence
- anomaly indicators

Standard Control Formulation

$$u_t = \pi(z_t, v_t)$$

Issue

If:

$$\frac{\partial v_t}{\partial \eta_t} > 0 \quad \text{and} \quad \frac{\partial u_t}{\partial v_t} > 0$$

then:

$$\eta_t \rightarrow v_t \rightarrow u_t$$

Thus, measurement noise propagates into control action.

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3. SVS Principle

We impose the constraint:

$$u_t = \pi(z_t)$$

$$\frac{\partial u_t}{\partial v_t} = 0$$

Interpretation

- z_t: physical system representation
- v_t: epistemic assessment

These must be **structurally separated**.

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4. Architecture

The system is decomposed into two pathways:

State Path

y_t \rightarrow z_t \rightarrow u_t

Valuation Path

y_t \rightarrow v_t \rightarrow m_t

with meta-control:

m_t = \mu(v_t), \quad u_t = \pi_{m_t}(z_t)

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Constraint

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v_t \not\rightarrow u_t
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5. Integration with Safety-Constrained Control

Let:

(z_t, u_t) \in \mathcal{S}_\phi

with projection:

u_t^{safe} = \Pi_{\mathcal{S}_\phi}(z_t, u_t)

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SVS Requirement

- \mathcal{S}_\phi independent of v_t
- v_t may influence:
  - margin selection
  - mode switching

but not:

- instantaneous constraint structure

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6. Application to Plasma Control

Plasma control systems (e.g., tokamak environments) exhibit:

- nonlinear dynamics
- uncertain diagnostics

• tight operational boundaries

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Typical Issue

Uncertainty in diagnostics influences control indirectly, leading to:

• oscillatory actuator behavior
• overcompensation
• premature constraint activation

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SVS Reformulation

• state: reconstructed plasma parameters z_t
• valuation: diagnostic uncertainty v_t

Control:

u_t = \pi(z_t)

Valuation:

• adjusts mode
• tightens margins
• triggers diagnostics

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Expected Effects

• reduced noise sensitivity
• improved stability near limits
• clearer separation of model error and system dynamics

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7. Relation to Existing Work

SVS is compatible with:

• Model Predictive Control (MPC)
• robust control
• observer-based estimation
• safety kernel architectures

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Position

SVS is not a new controller, but:

a constraint on information flow in control systems.

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8. Discussion

The SVS principle introduces a minimal but fundamental restriction:

- uncertainty must not act as a direct control signal

This reframes uncertainty as:

- a supervisory input
- not an operational driver

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9. Conclusion

We proposed the SVS principle as a structural constraint separating state and valuation in control systems.

This separation:

- improves stability
- reduces noise amplification
- enhances interpretability

The approach is general and applicable across domains, with particular relevance for safety-critical systems such as plasma control.

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10. Outlook

Future work includes:

- simulation studies with synthetic noise
- integration into MPC frameworks
- evaluation in plasma control scenarios
- formal stability analysis